JOURNAL OF ANIMAL SCIENCE
The Premier Journal and Leading Source of New Knowledge and Perspective in Animal Science

The tryptophan requirement of nursery pigs

A. C. Guzik, L. L. Southern, T. D. Bidner and B. J. Kerr

J Anim Sci 2002. 80:2646-2655.

The tryptophan requirement of nursery pigs[1,2]

A. C. Guzik*, L. L. Southern,*[3] T. D. Bidner*, and B. J. Kerr†

*Department of Animal Science, Louisiana State University Agricultural Center, Baton Rouge 70803 and †USDA-ARS-SOMMRU, National Swine Research & Information Center, 2150 Pammel Drive, Room 2202, Ames, IA 50011

ABSTRACT: Five experiments were conducted to determine the true digestible Trp (dTrp) requirement of nursery pigs. Treatments were replicated with four or five pens of five or six pigs each. Pigs were weaned at 21 (Exp. 1, 2, and 5) or 19 d (Exp. 3 and 4), and fed common diets for various times and then experimental diets for 8 (Exp. 1), 13 (Exp. 2 and 3), or 14 d (Exp. 4 and 5). Experiment 1 (160 pigs, initial and final BW of 8.4 and 11.4 kg) evaluated six protein sources low in Trp relative to a positive control diet to identify the protein source to be used in subsequent experiments. The results indicated that a diet with Canadian field peas (CFP) supplemented with Trp resulted in ADG, ADFI, and gain:feed (GF) equal to ($P > 0.10$) the positive control diet. In Exp. 2, 75 pigs (initial and final BW of 13.2 and 19.2 kg) were fed 1) Trp-deficient diet (0.13% dTrp) with CFP, 2) Diet 1 with added Trp (0.23% dTrp), or 3) positive control diet (0.22% dTrp). Daily gain, ADFI, and GF were decreased ($P < 0.01$) in pigs fed Diet 1 compared with pigs fed Diets 2 and 3, but ADG, ADFI, and GF were equal ($P > 0.10$) in pigs fed Diets 2 and 3. Experiments 3 (180 pigs, initial and final BW of 5.2 and 7.3 kg), 4 (120 pigs, initial and final BW of 6.3 and 10.2 kg), and 5 (144 pigs, initial and final BW of 10.3 and 15.7 kg) were conducted to estimate the dTrp requirement of nursery pigs with diets using CFP as a primary protein source. The diets used in Exp. 3, 4, and 5 contained 1.35, 1.19, or 1.01% dLys, respectively, and other amino acids were provided at 105% the ratio relative to Lys. Response variables were ADG, ADFI, GF, and plasma urea N concentrations, and data were analyzed using the broken-line model. The levels of dTrp in the diets for Exp. 3 (Phase I, 5.2 to 7.3 kg) were 0.14, 0.17, 0.20, 0.23, 0.26, and 0.29%. The average dTrp requirement was estimated to be 0.21% (0.24% total Trp). The levels of dTrp in the diets for Exp. 4 (Phase II, 6.3 to 10.2 kg) were 0.13, 0.16, 0.19, 0.22, 0.25, and 0.28%. The average dTrp requirement was estimated to be 0.20% (0.23% total Trp). The levels of dTrp in the diets for Exp. 5 (Phase III, 10.3 to 15.7 kg) were 0.130, 0.155, 0.180, 0.205, 0.230, and 0.255%. The average dTrp requirement was estimated to be 0.18% (0.22% total Trp). These results indicate that the true dTrp requirement is 0.21, 0.20, and 0.18% for Phase I (5.2 to 7.3 kg), II (6.3 to 10.2 kg), and III (10.3 to 15.7 kg) nursery pigs, respectively.

Key Words: Pigs, Requirements, Tryptophan

 J. Anim. Sci. 2002. 80:2646–2655

Introduction

Tryptophan is an essential dietary amino acid that is equally second or third limiting in typical diets for pigs. In diets consisting primarily of corn, it is the first limiting amino acid because of the low Trp content and availability in corn (Baker et al., 1969). The Trp content in the diet is important for optimal growth performance, and reliable requirement estimates are imperative when formulating diets based on the ideal protein concept. The Trp requirement of nursery pigs has been studied with results varying from study to study. Protein levels, various feedstuffs, and Trp digestibility of the feedstuffs may be reasons for this variation. Most of the research conducted thus far has estimated the total Trp requirement. Review of published research indicates that the Trp requirements for 5- to 20-kg nursery pigs range from 0.14 to 0.25% total Trp. Burgoon et al. (1992) and Schutte et al. (1995) were among the first to estimate the true digestible Trp (dTrp) requirement of young pigs. Recent research has estimated dTrp requirements because this estimation may be more accurate because of the variation in digestibility of Trp in feedstuffs.

Although there have been no estimates of the dTrp requirement of nursery pigs that segregate pigs into

[1]Approved for publication by the Director of the Louisiana Agric. Exp. Sta. as manuscript publ. no. 2002-11-0108.

[2]Research supported in part with funds and supply of amino acids by Nutri-Quest Inc., Chesterfield, MO 63017.

[3]Correspondence: lsouthern@agctr.lsu.edu.

Received September 14, 2001.

Accepted June 19, 2002.

Phase I, II, and III, which is typical of current feeding systems, the NRC (1998) provides recommendations for the requirement for Trp based on a summary of work from various scientists. The estimates for pigs weighing 3 to 5 kg, 5 to 10 kg, and 10 to 20 kg are 0.24, 0.22, and 0.18% dTrp, respectively (NRC, 1998). With the lack of empirical data, accurate Trp requirement estimates to optimize growth performance through diet formulation are necessary. The objective of this research was to estimate the dTrp requirement of nursery pigs immediately after weaning (Phase I), of pigs from 7 to 21 d postweaning (Phase II), and of pigs from 21 to 35 d postweaning (Phase III).

Materials and Methods

General

The experiments were approved by the University Animal Care and Use Committee.

Five experiments were conducted to estimate the dTrp requirement of nursery pigs. Yorkshire, Yorkshire × Landrace, or Yorkshire × Landrace × Duroc pigs from the Louisiana State University Agricultural Center Swine Unit were used in each experiment. They were housed in an environmentally controlled modular building with under-floor flush and hard plastic slotted floors. Pigs and their environment were monitored twice daily. Pigs were provided ad libitum access to feed and water throughout the experiments. Pigs in each experiment were allotted to treatments on the basis of weight, and gender and ancestry were equalized across treatments in a randomized complete block design. Pens contained an approximately equal number of barrows and gilts.

The diets in all experiments met or exceeded the nutrient requirements (with the exception of Trp for experimental purposes) of nursery pigs (NRC, 1998). Amino acids were provided at a minimum of 105% the ratio relative to Lys (NRC, 1998). The Phase I, II, and III diets contained 1.35, 1.19, or 1.01% true digestible Lys. We will refer to Phase I diets as those fed immediately after weaning, Phase II diets as those fed from 7 to 21 d postweaning, and Phase III diets as those fed from 21 to 35 d postweaning. We also will refer to Phase I, II, and III pigs as those pigs fed Phase I, II, and III diets.

In Exp. 1, diet formulations using corn, soybean meal (**SBM**), corn gluten meal, and feather meal were based on the amino acid values and true ileal digestibility coefficients in NRC (1998). Amino acid values and true digestibility coefficients for Canadian field peas (**CFP**) and oatmeal were obtained by using the NRC (1998) values for pea seeds and oat groats, respectively. Amino acid values and apparent digestibility coefficients for spray-dried porcine plasma were obtained by using the NRC (1998) values for spray-dried blood plasma. Gelatin was analyzed for amino acids (Table 1), and all amino acids were assumed to have a true digestibility coefficient of 95%.

In Exp. 2, 3, 4, and 5, all ingredients were analyzed for amino acids and true digestibility coefficients (except for spray-dried porcine plasma) from NRC (1998) were used. Apparent ileal digestibility coefficients were used for spray-dried porcine plasma (NRC, 1998), and a digestibility coefficient of 95% was used for gelatin. The amino acid composition of the ingredients (Table 1) was determined after acid hydrolysis (AOAC, 1990). Total sulfur amino acid content was determined after performic acid oxidation followed by acid hydrolysis (AOAC, 1990). Tryptophan content was determined after alkaline hydrolysis (AOAC, 1990).

Experiment 1

The purpose of this experiment was to evaluate Trp-deficient diets containing various protein sources that, when supplemented with crystalline L-Trp, would result in growth performance similar to that of a positive control diet. The diet with optimal results would be used in subsequent requirement studies. One hundred sixty nursery pigs were allotted to seven dietary treatments: 1) positive control (**PC**), 2) oatmeal, 3) spray-dried porcine plasma, 4) gelatin, 5) corn gluten meal, 6) CFP, or 7) feather meal as primary protein sources (Table 2). The pigs were weaned at an average age of 21 d, and they were fed a Phase I diet for 7 d before the experiment was initiated. This Phase I diet was formulated to provide 1.6% total Lys and 0.31% total Trp, and it contained 38% corn, 21% SBM, 15% whey, 5% lactose, 5% spray-dried porcine plasma, 8% fish meal, 3,000 ppm Zn as ZnO, and an antibiotic, and it was fortified with vitamins and minerals to exceed the nutrient requirements of 3- to 5-kg pigs (NRC, 1998). The average initial and final BW were 8.4 and 11.4 kg. Each treatment was replicated with four pens of five pigs each. The diets were pelleted and fed for 8 d. Response variables included ADG, ADFI, and gain:feed.

Experiment 2

A preliminary experiment was conducted with 75 pigs weighing 13.2- to 19.2-kg (Phase III) to ensure that a CFP Trp-deficient (0.14%) diet, when supplemented with crystalline L-Trp, would result in growth performance similar to a conventional corn-SBM diet. Pigs were weaned at 21 d of age, and they were fed a Phase I diet for 7 d and a Phase II diet for 14 d before the experiment was initiated. The Phase I diet was the same as that used in Exp. 1. The Phase II diet was formulated to provide 1.5% total Lys and 0.29% total Trp, and it contained 46% corn, 29% SBM, 10% whey, 8% fish meal, 3,000 ppm Zn as ZnO, and an antibiotic, and it was fortified with vitamins and minerals to exceed the nutrient requirements of 5- to 10-kg pigs (NRC, 1998). Pigs were allotted to three dietary treatments derived from the Phase III basal diet described in Table 3 and a "typical" positive control. Each treatment was replicated with five pens of six pigs each. Treatments

Table 1. Analyzed amino acid composition (%) of ingredients[a]

	Ingredient							
Nutrient	Corn[b]	Corn[c]	CFP	CGM	FM	SDPP	Gelatin[d]	Whey
Arginine	0.40	0.43	1.66	2.02	3.73	4.43	7.79	0.22
Histidine	0.21	0.23	0.47	1.23	1.50	2.62	0.81	0.16
Isoleucine	0.27	0.26	0.87	2.37	2.43	2.87	1.09	0.70
Leucine	0.95	0.96	1.49	10.40	4.36	7.80	2.59	1.18
Lysine	0.26	0.25	1.51	1.09	4.61	6.89	3.69	0.73
Methionine	0.18	0.16	0.20	1.64	1.72	0.73	0.95	0.17
Cystine	0.19	0.18	0.32	1.26	0.55	2.56	0.16	0.27
Phenylalanine	0.39	0.38	0.97	3.98	2.36	4.44	1.86	0.33
Tyrosine	0.25	0.25	0.62	3.28	1.86	4.16	0.68	0.30
Threonine	0.29	0.28	0.77	2.17	2.49	4.60	1.67	0.73
Tryptophan	0.06	0.06	0.16	0.38	0.71	1.43	0.04	0.21
Valine	0.39	0.40	0.91	2.90	2.98	5.10	2.26	0.58

[a]CFP = Canadian field peas; CGM = corn gluten meal; FM = feather meal, SDPP = spray-dried porcine plasma.
[b]Corn used for Exp. 3.
[c]Corn was used for Exp. 2, 4, and 5.
[d]Gelatin used in Exp. 1.

consisted of 1) CFP negative control (**NC**), 2) NC + Trp, or 3) corn-SBM PC. The experimental diets were fed for 13 d in meal form. Response variables included ADG, ADFI, and gain:feed.

Experiment 3

One hundred eighty pigs (weaned at 19 d of age) were allotted to six dietary treatments derived from the Phase I basal diet described in Table 3. Pigs had an initial and final BW of 5.2 and 7.3 kg. Each treatment was replicated with five pens of six pigs each. Diets were supplemented with crystalline L-Trp at increments of 0.03% to give six treatments containing 0.14, 0.17, 0.20, 0.23, 0.26, or 0.29% dTrp. The experimental diets were fed in meal form for 13 d. Response variables were ADG, ADFI, gain:feed, and plasma urea N (**PUN**) concentrations.

Experiment 4

One hundred twenty pigs were allotted to six dietary treatments derived from the Phase II basal diet described in Table 3. The pigs were weaned at 19 d of age and were fed the same Phase I diet used in Exp. 1 for 7 d before the experiment was initiated. Pigs had an initial and final BW of 6.3 and 10.2 kg. Each treatment was replicated with four pens of five pigs each. Diets were supplemented with crystalline L-Trp at 0.03% increments to give six treatments containing 0.13, 0.16, 0.19, 0.22, 0.25, or 0.28% dTrp. The experimental diets were fed in meal form for 14 d. Response variables were ADG, ADFI, gain:feed, and PUN concentrations.

Experiment 5

One hundred forty-four pigs were allotted to six dietary treatments derived from the Phase III basal diet described in Table 3. The pigs were weaned at 21 d of age and were fed the same Phase I and II diets used in Exp. 2 for 7 and 14 d, respectively, before the experiment was initiated. Pigs had an initial and final BW of 10.3 and 15.7 kg. Each treatment was replicated with four pens of six pigs each. Diets were supplemented with crystalline L-Trp at 0.025% increments to give six treatments containing 0.130, 0.155, 0.180, 0.205, 0.230, or 0.255% dTrp. The experimental diets were fed in meal form for 14 d. Response variables were ADG, ADFI, gain:feed, and PUN concentrations.

Blood Sampling

At the termination of Exp. 3, 4, and 5, blood was collected via the anterior vena cava. Pigs had access to feed before bleeding. Blood for each pig was placed in 7-mL tubes (Monoject, Sherwood Medical, St. Louis, MO) containing 17.5 mg of sodium fluoride and 14.0 mg of potassium oxalate. Samples were placed on ice for 2 h before centrifugation at 1,600 × g at 4°C for 20 min. Plasma was collected after centrifugation and samples were frozen until analysis. Plasma was analyzed for PUN concentrations by the methods of Laborde et al. (1995).

Statistical Analysis

In each experiment, data were analyzed by ANOVA as a randomized complete block design using the GLM procedures of SAS (SAS Inst. Inc., Cary, NC). In Exp. 1 and 2, the LSD procedure of SAS was used to determine differences among treatment means. In Exp. 3, 4, and 5, contrasts were used to determine linear and quadratic effects of Trp. The two-slope, broken-line regression model was used for all response variables to obtain an estimate of the dTrp requirement (Robbins, 1986). The pen of pigs served as the experimental unit for all data.

Table 2. Composition of experimental diets on an as-fed basis, Exp. 1

Ingredient, %	PC[a]	Oatmeal	SDPP[b]	Gelatin[c]	CGM[d]	CFP[e]	FM[f]
Corn	47.140	47.869	61.261	45.104	54.288	36.915	63.035
Soybean meal (47.5%)	30.077	—	—	—	1.293	—	—
Oatmeal	—	8.432	—	—	—	—	—
Spray-dried porcine plasma[b]	—	—	1.500	—	—	—	—
Gelatin[c]	—	—	—	5.000	—	—	—
Canadian field peas	—	—	—	—	—	30.000	—
Feather meal	—	—	—	—	—	—	10.822
Fish meal	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Corn gluten meal	1.119	22.383	14.212	28.454	23.137	8.973	—
Dried whey	10.000	10.000	10.000	10.000	10.000	10.000	10.000
Monocalcium phosphate	1.102	1.471	1.506	1.545	1.492	1.506	1.645
Limestone	0.742	0.820	0.818	0.738	0.812	0.763	0.693
Fat[g]	1.775	—	1.372	0.455	—	2.733	4.549
Sodium bentonite[h]	0.500	0.500	0.500	0.500	0.500	0.500	0.500
Salt	0.500	0.500	0.500	0.500	0.500	0.500	0.500
Vitamin premix[i]	0.500	0.500	0.500	0.500	0.500	0.500	0.500
Mineral premix[j]	0.100	0.100	0.100	0.100	0.100	0.100	0.100
Se premix[k]	0.050	0.050	0.050	0.050	0.050	0.050	0.050
ZMC-Fe[l]	0.100	0.100	0.100	0.100	0.100	0.100	0.100
ZnO	0.420	0.420	0.420	0.420	0.420	0.420	0.420
Antibiotic[m]	0.750	0.750	0.750	0.750	0.750	0.750	0.750
Choline chloride	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Flavor[n]	0.075	0.075	0.075	0.075	0.075	0.075	0.075
L-TRP	—	0.150	0.150	0.150	0.150	0.150	0.150
L-LYS·HCl	—	0.749	0.736	0.509	0.722	0.452	0.793
L-ILE	—	—	0.050	—	—	0.030	0.006
L-THR	—	0.081	0.165	—	0.061	0.176	0.129
DL-MET	—	—	0.060	—	—	0.125	—
L-VAL	—	—	0.111	—	—	0.133	—
L-HIS	—	—	0.013	—	—	—	0.134
Calculated composition, %							
ME, kcal/kg	3,300	3,300	3,300	3,300	3,300	3,300	3,300
t Lys	1.330	1.298	1.291	1.308	1.299	1.308	1.329
t Trp	0.298	0.320	0.312	0.324	0.320	0.324	0.303
t Thr	0.910	0.916	0.894	1.001	0.917	0.897	0.917
t Ile	0.994	0.916	0.790	1.072	0.934	0.795	0.779
t Val	1.120	1.074	1.021	1.285	1.089	1.023	1.082
t TSAA	0.825	0.938	0.854	1.099	0.965	0.803	0.724
d Lys[o]	1.190	1.190	1.190	1.190	1.190	1.190	1.190
d Trp	0.260	0.280	0.280	0.280	0.280	0.280	0.280
d Thr	0.780	0.780	0.780	0.850	0.780	0.780	0.780
d Ile	0.883	0.785	0.690	0.922	0.802	0.690	0.690
d Val	0.983	0.890	0.880	1.074	0.906	0.880	0.926
d Phe + Tyr	1.702	1.981	1.579	2.373	2.029	1.430	1.201
d Leu	1.768	2.779	2.181	3.362	2.874	1.806	1.447
d His	0.549	0.441	0.400	0.519	0.460	0.409	0.400
d Arg	1.400	0.810	0.659	1.206	0.828	0.983	0.935
d TSAA	0.732	0.819	0.710	0.964	0.843	0.710	0.724
Ca	0.900	0.900	0.900	0.900	0.900	0.900	0.900
P	0.800	0.800	0.800	0.800	0.800	0.800	0.800

[a]Positive control.
[b]AP 920, American Protein Corporation, Ames, IA 30041.
[c]Dynagel, Calumet City, IL 60409.
[d]Corn gluten meal.
[e]Canadian field peas.
[f]Feather meal.
[g]Provided 99% crude fat, Fat Pak 100, Milk Specialties Co., Dundee, IL 60118.
[h]AB-20, provided by Prince Agri Products, Inc., Quincy, IL 62306.
[i]Provided the following per kilogram of diet: vitamin A, 11,023 IU; vitamin D_3, 3,307 IU; vitamin E, 88 IU; menadione (menadione pyrimidinol bisulfite) 8.3 mg; riboflavin, 13 mg; pantothenic acid, 50 mg; niacin, 88 mg; vitamin B_{12}, 61 μg; biotin, 441 μg; choline (as choline chloride), 882 mg; folic acid, 3.3 mg, pyridoxine, 4.41 mg; thiamin, 4.41 mg; and vitamin C, 110 μg.
[j]Provided the following per kilogram of diet: Zn (zinc sulfate), 127 mg; Fe (ferrous sulfate monohydrate), 127 mg; Mn (manganese sulfate), 20 mg; Cu (copper sulfate), 12.7 mg; I (calcium iodate), 0.80 mg.
[k]Provided 0.3 mg Se (sodium selenite) per kilogram of diet.
[l]Provided the following per kilogram of diet: Zn, 40 mg; Mn, 7.5 mg; Cu, 6 mg; Fe, 25 mg, Optimin Baby Pig, DuCoa, Highland, IL 62249.
[m]Neo-Terra 10/10, Oxytetracycline (from oxytetracycline quaternary salt) equivalent to oxytetracycline hydrochloride 22 g/kg, Nutra Blend Corporation, Neosho, MO 64850.
[n]Dried strawberry, Feed Flavors, Inc., Wheeling, IL 60090.
[o]The digestible amino acid levels were estimated by using the true digestibility coefficients in NRC (1998).

Table 3. Composition of experimental diets on an as-fed basis, Exp. 2, 3, 4, and 5

Ingredient	Phase I	Phase II	Phase III
Corn	43.270	34.600	41.890
Canadian field peas	7.000	33.720	29.200
Dried whey	15.000	10.000	5.000
Fish meal	3.500	5.000	5.000
Corn gluten meal	7.950	6.760	13.060
Spray-dried porcine plasma[a]	3.500	—	—
Lactose	9.380	—	—
Monocalcium phosphate	1.630	1.510	1.060
Limestone	0.880	0.750	0.770
Fat[b]	2.720	3.120	0.780
Salt	0.250	0.500	0.500
Vitamin premix[c]	0.500	0.500	0.500
Mineral premix[d]	0.100	0.100	0.100
Se premix[e]	0.050	0.050	0.050
Sodium bentonite[f]	0.500	0.500	0.500
ZMC-Fe[g]	0.100	0.100	—
ZnO	0.420	0.420	—
Antibiotic[h]	0.750	0.750	0.750
L-LYS·HCl	0.810	0.420	0.220
Choline chloride	0.050	0.050	—
Flavor[i]	0.075	0.075	0.075
DL-MET	0.220	0.165	—
L-THR	0.284	0.196	0.059
L-VAL	0.252	0.160	—
L-ILE	0.199	0.054	—
L-HIS	0.112	—	—
Cornstarch	0.500	0.500	0.500
Calculated composition, %[j]			
ME, kcal/kg	3,300	3,300	3,300
t Lys	1.461 (1.400)	1.309 (1.270)	1.130 (1.110)
t Trp	0.172 (0.190)	0.163 (0.170)	0.166 (0.150)
t Thr	0.995 (0.930)	0.894 (0.870)	0.840 (0.820)
t Ile	0.858 (0.820)	0.790 (0.760)	0.845 (0.810)
t Val	1.084 (1.040)	1.015 (1.010)	0.989 (0.970)
t TSAA	0.873 (0.820)	0.798 (0.760)	0.775 (0.740)
d Lys[k]	1.350	1.190	1.010
d Trp	0.140	0.130	0.130
d Thr	0.880	0.780	0.715
d Ile	0.767	0.690	0.728
d Val	0.956	0.880	0.828
d Phe + Tyr	1.323	1.333	1.671
d Leu	1.720	1.637	2.160
d His	0.452	0.400	0.449
d Arg	0.679	0.999	1.047
d TSAA	0.798	0.710	0.670
Ca	0.900	0.900	0.800
P	0.800	0.800	0.700

[a]AP 920, American Protein Corporation, Ames, IA 30041.
[b]Provided 99% crude fat, Fat Pak 100, Milk Specialties Co., Dundee, IL 60118.
[c]Provided the following per kilogram of diet: vitamin A, 11,023 IU; vitamin D_3, 3,307 IU; vitamin E, 88 IU; menadione (menadione pyrimidinol bisulfite) 8.3 mg; riboflavin, 13 mg; pantothenic acid, 50 mg; niacin, 88 mg; vitamin B_{12}, 61 μg; biotin, 441 μg; choline (as choline chloride), 882 mg; folic acid, 3.3 mg, pyridoxine, 4.41 mg; thiamin, 4.41 mg; and vitamin C, 110 μg.
[d]Provided the following per kilogram of diet: Zn (zinc sulfate), 127 mg; Fe (ferrous sulfate monohydrate), 127 mg; Mn (manganese sulfate), 20 mg; Cu (copper sulfate), 12.7 mg; I (calcium iodate), 0.80 mg.
[e]Provided 0.3 mg Se (sodium selenite) per kilogram of diet.
[f]AB-20, provided by Prince Agri Products, Inc., Quincy, IL 62306.
[g]Provided the following per kilogram of diet: Zn, 40 mg; Mn, 7.5 mg; Cu, 6 mg; Fe, 25 mg, Optimin Baby Pig, DuCoa, Highland, IL 62249.
[h]Neo-Terra 10/10, Oxytetracycline (from oxytetracycline quaternary salt) equivalent to oxytetracycline hydrochloride 22 g/kg, Nutra Blend Corporation, Neosho, MO 64850.
[i]Dried strawberry, Feed Flavors, Inc., Wheeling, IL 60090.
[j]Analyzed values are shown in parentheses.
[k]The digestible amino acid levels were estimated by using the true digestibility coefficients in NRC (1998).

Table 4. Growth performance of Phase II pigs fed various protein sources, Exp. 1[a]

Diet	ADG	ADFI	Gain:feed
Positive control	434	490	884
Oatmeal	340	421	812
Spray-dried porcine plasma[b]	312	395	786
Gelatin[c]	374	478	785
Corn gluten meal	403	483	823
Canadian field peas	448	498	900
Feather meal	335	412	819
Pooled SEM	32	27	41
Positive Control vs other diets[d]		$P > F$	
Oatmeal	0.06	0.09	NS
Spray-dried porcine plasma	0.02	0.03	0.12
Gelatin	NS	NS	0.11
Corn gluten meal	NS	NS	NS
Canadian field peas	NS	NS	NS
Feather meal	0.05	0.06	NS

[a]Data are means of four replicates of five pigs each. Average initial and final BW were 8.4 and 11.4 kg. Average age of pigs was 21 d at weaning. The experimental period was 8 d.
[b]AP 920, American Protein Corporation, Ames, IA 30041.
[c]Dynagel, Calumet City, IL 60409.
[d]NS = not significant, $P > 0.12$.

Results

Experiment 1 (8.4- to 11.4-kg pigs)

Pigs fed the diet containing CFP had ADG, ADFI, and gain:feed similar ($P > 0.10$) to those fed the conventional corn-SBM diet (Table 4). Pigs fed diets containing oatmeal, spray-dried porcine plasma, or feather meal as protein sources had reduced ($P < 0.10$) ADG and ADFI, whereas a gelatin-based diet tended to decrease ($P = 0.11$) gain:feed. Results from this study suggest that CFP are a quality protein source for nursery pigs. This experiment served as a preliminary study to evaluate various protein sources.

Experiment 2 (13.2- to 19.2-kg pigs)

Pigs fed the CFP-diet supplemented with crystalline L-Trp had growth performance similar ($P > 0.10$) to those fed the PC diet (Table 5). Pigs fed the CFP-without L-Trp supplementation had consistently reduced ($P < 0.01$) ADG, ADFI, and gain:feed compared with pigs fed the CFP + Trp or the PC diet. This experiment validated the Trp-deficient CFP diet, and this diet was used in subsequent Trp-requirement studies.

Experiment 3 (5.2- to 7.3-kg pigs)

Overall ADG, ADFI, and gain:feed were increased linearly ($P < 0.01$) and quadratically ($P < 0.04$) as the

Table 5. Growth performance of Phase III pigs fed a positive control diet or a diet deficient in Trp or this diet supplemented with Trp, Exp. 2[a]

Diet	CFP[b]	CFP + Trp	Positive control	Pooled SEM	$P > F$
ADG, g					
d 0 to 7	161[c]	525[d]	539[d]	20	0.01
d 7 to 13	318[c]	665[d]	668[d]	24	0.01
d 0 to 13	233[c]	589[d]	599[d]	19	0.01
ADFI, g					
d 0 to 7	522[c]	794[d]	857[d]	32	0.01
d 7 to 13	649[c]	1,036[d]	1,123[d]	48	0.01
d 0 to 13	581[c]	906[d]	980[d]	36	0.01
Gain:feed, g/kg					
d 0 to 7	308[c]	634[d]	642[d]	26	0.01
d 7 to 13	488[c]	647[d]	595[e]	18	0.10
d 0 to 13	401[c]	627[d]	613[d]	15	0.01

[a]Data are means of five replicates of five pigs each. Average initial and final BW were 13.2 and 19.2 kg. Average age of pigs was 21 d at weaning.
[b]Canadian field peas.
[c,d,e]Means within a row with different superscripts differ by the P value shown.

Table 6. Growth performance of Phase I pigs fed graded levels of Trp, Exp. 3[a]

Diet	Digestible tryptophan						SEM	$P > F$[b]	
	0.14%	0.17%	0.20%	0.23%	0.26%	0.29%		Lin	Quad
ADG, g									
d 0 to 8	79	117	151	155	138	134	17	0.04	0.02
d 8 to 13	127	218	221	268	281	251	16	0.01	0.01
d 0 to 13	98	156	178	198	193	179	12	0.01	0.01
ADFI, g									
d 0 to 8	185	232	227	235	241	233	20	NS	NS
d 8 to 13	286	352	389	430	440	431	15	0.01	0.01
d 0 to 13	224	279	289	310	318	309	15	0.01	0.04
Gain:feed, g/kg									
d 0 to 8	433	492	662	650	569	578	42	0.02	0.01
d 8 to 13	443	629	572	621	637	586	50	0.07	0.06
d 0 to 13	437	562	617	638	608	579	30	0.01	0.01
PUN, mmol/L									
d 13	2.72	1.13	0.57	0.60	0.64	0.49	0.10	0.01	0.01

[a]Data are means of five replicates of six pigs each. Average initial and final BW were 5.2 and 7.3 kg. Average age of pigs was 19 d at weaning.
[b]NS = not significant, $P > 0.10$.

dTrp content increased from 0.14 to 0.29% in Phase I pigs (Table 6). Broken-line analysis estimated the optimum dTrp requirement to be 0.208 and 0.217% for ADG and gain:feed during wk 1 of the experiment. Overall, estimates of dTrp requirement were 0.215, 0.210, and 0.182% for ADG, gain:feed, and PUN concentrations, respectively. The average of these values yields an estimate of 0.21% dTrp (0.24% total Trp) for optimum growth performance of Phase I pigs weighing 5.2 to 7.3 kg.

Experiment 4 (6.3- to 10.2-kg pigs)

Overall ADG, ADFI, and gain:feed were increased linearly ($P < 0.01$) and quadratically ($P < 0.08$) as the dTrp content increased from 0.13 to 0.28% in Phase II pigs (Table 7). Broken-line analysis estimated the optimum dTrp requirement to be 0.184, 0.179, 0.207, and 0.215% for overall ADG, ADFI, gain:feed, and PUN concentrations, respectively. The average of these values yields an estimate of 0.20% dTrp (0.23% total Trp) for optimum growth of Phase II pigs weighing 6.3 to 10.2 kg.

Experiment 5 (10.3- to 15.7-kg pigs)

Overall ADG, ADFI, and gain:feed were increased linearly ($P < 0.03$) and quadratically ($P < 0.01$) as the dTrp content increased from 0.13 to 0.255% in Phase III pigs (Table 8). Broken-line analysis estimated the

Table 7. Growth performance of Phase II pigs fed graded levels of Trp, Exp. 4[a]

Diet	Digestible tryptophan						SEM	$P > F$[b]	
	0.13%	0.16%	0.19%	0.22%	0.25%	0.28%		Lin	Quad
ADG, g									
d 0 to 7	88	206	279	294	280	271	20	0.01	0.01
d 7 to 14	183	280	372	359	349	368	28	0.01	0.03
d 0 to 14	136	243	326	327	315	320	19	0.01	0.01
ADFI, g									
d 0 to 7	284	423	452	426	379	387	31	NS	0.01
d 7 to 14	371	499	646	593	604	599	30	0.01	0.01
d 0 to 14	327	461	549	510	491	493	21	0.01	0.01
Gain:feed, g/kg									
d 0 to 7	325	495	617	681	741	706	52	0.01	0.03
d 7 to 14	502	566	565	629	579	620	50	NS	NS
d 0 to 14	422	529	589	650	636	652	34	0.01	0.08
PUN, mmol/L									
d 14	3.72	3.19	2.94	2.63	2.68	2.97	0.25	0.02	0.05

[a]Data are means of four replicates of five pigs each. Average initial and final BW were 6.3 and 10.2 kg. Average age of pigs was 19 d at weaning.
[b]NS = not significant, $P > 0.10$.

Table 8. Growth performance of Phase III pigs fed graded levels of Trp, Exp. 5[a]

	Digestible tryptophan							$P > F$[b]	
Diet	0.130%	0.155%	0.180%	0.205%	0.230%	0.255%	SEM	Lin	Quad
ADG, g									
d 0 to 7	202	259	416	445	537	381	44	0.01	0.01
d 7 to 14	254	404	522	400	316	475	56	NS	NS
d 0 to 14	228	331	469	423	427	428	23	0.01	0.01
ADFI, g									
d 0 to 7	510	556	668	709	844	748	23	0.01	0.02
d 7 to 14	553	727	877	778	718	917	43	0.01	0.09
d 0 to 14	532	640	772	743	781	832	24	0.01	0.01
Gain:feed, g/kg									
d 0 to 7	400	463	638	631	633	502	63	0.08	0.02
d 7 to 14	459	551	596	507	434	517	59	NS	NS
d 0 to 14	429	514	610	567	546	513	24	0.03	0.01
PUN, mmol/L									
d 14	3.75	2.74	2.33	2.41	2.60	2.77	0.11	0.01	0.01

[a]Data are means of four replicates of six pigs each. Average initial and final BW were 10.3 and 15.7 kg. Average age of pigs was 21 d at weaning.
[b]NS = not significant, $P > 0.10$.

optimum dTrp requirement to be 0.18, 0.18, 0.181, and 0.168% for overall ADG, ADFI, gain:feed, and PUN concentrations, respectively. The average of these values yields an estimate of 0.18% dTrp (0.22% total Trp) for optimum growth of Phase III pigs weighing 10.3 to 15.7 kg.

Discussion

The purpose of Exp. 1 was to compare various protein sources to a positive control diet. This experiment was conducted after three previous attempts to develop a gelatin-based Trp-deficient diet failed (Table 9). In all

Table 9. Growth performance of pigs fed a gelatin-based tryptophan-deficient diet, the deficient diet with supplemental L-Trp, and a positive control diet

Diet	Negative control	NC + Trp	Positive control	Pooled SEM	$P > F$
ADG, g (d 0 to 14)					
Preliminary Exp. 1[a]	8[d]	342[e]	444[f]	22	0.01
Preliminary Exp. 2[b]	17[d]	301[e]	342[f]	12	0.05
Preliminary Exp. 3[c]	70[d]	397[e]	482[f]	22	0.03
ADFI, g (d 0 to 14)					
Preliminary Exp. 1	290[d]	605[e]	763[f]	33	0.01
Preliminary Exp. 2	170[d]	444[e]	505[f]	14	0.02
Preliminary Exp. 3	337[d]	697[e]	772[e]	38	0.01
Gain:feed, g/kg (d 0 to 14)					
Preliminary Exp. 1	25[d]	570[e]	581[e]	32	0.01
Preliminary Exp. 2	63[d]	679[e]	677[e]	64	0.01
Preliminary Exp. 3	203[d]	572[e]	629[f]	18	0.05
Plasma urea N (d 14)					
Preliminary Exp. 1	4.95[d]	4.28[d]	2.47[e]	0.33	0.01
Preliminary Exp. 2	5.71[d]	4.36[de]	3.32[e]	0.45	0.07

[a]Data are means of six replicates of five pigs each. Average initial and final BW were 10.8 and 15.6 kg. Average age of pigs was 21 d at weaning. Diet was similar to Phase III diet in Table 3 with the exception of no corn gluten meal, 68% corn, 16% gelatin, and 2.5% whey. Minor changes were made in some of the other ingredients.
[b]Data are means of six replicates of four pigs each. Average initial and final BW were 7.0 and 10.1 kg. Average age of pigs was 23 d at weaning. Diet was similar to Phase II diet in Table 3 with the exception of 48% corn, 17% gelatin, 3% soybean meal and 5% corn gluten meal. Minor changes were made in some of the other ingredients.
[c]Data are means of six replicates of four pigs each. Average initial and final BW were 9.6 and 14.0 kg. Average age of pigs was 21 d at weaning. Diet was similar to Phase III diet in Table 3 with the exception of no corn gluten meal, 62% corn, 14% gelatin, 6.5% soybean meal, and 2.5% whey. Minor changes were made in some of the other ingredients.
[d,e,f]Means within a row with different superscripts differ by the P-value shown.

Table 10. Effects of protein level and(or) gelatin on growth performance of broiler chicks[a]

Diet	Lys[b] level, %	Gelatin %	ADG[c,d] g	ADFI[c] g	Gain:feed[c,e]
Positive control	1.12	0	35.48	49.38	718
Gelatin	1.12	5	33.84	49.09	691
Positive control	0.78	0	25.42	44.71	592
Gelatin	0.78	5	21.61	41.82	519
Pooled SEM			0.71	1.96	29

[a]Means are the average of seven replicates of five chicks (6 d posthatching) with initial and final BW of 109.1 and 398.2 g, respectively. The experimental period was 10 d.
[b]Diets were formulated on a digestible basis to adequate or deficient in Lys.
[c]Protein level effect, $P < 0.01$.
[d]Gelatin level effect, $P < 0.01$.
[e]Gelatin level effect, $P < 0.10$.

three experiments, the gelatin-based diet, when supplemented with L-Trp, failed to give growth performance equal to a positive control. A subsequent experiment with chickens fed protein-deficient or protein-adequate diets was conducted to evaluate the gelatin. Daily gain, ADFI, and gain:feed were decreased in chickens fed gelatin regardless of the protein adequacy of the diet (Table 10). Thus, from these preliminary experiments we concluded that the gelatin we were using did not result in optimum growth performance when added to diets formulated to be nutritionally adequate in all nutrients. Gelatin previously has been used as a protein source in Trp requirement studies. However, these researchers did not compare the gelatin-based diet to a conventional diet to validate it as a suitable Trp-deficient diet (Boomgaardt and Baker, 1973; Zimmerman, 1975; Leibholz, 1981).

There has been a lot of variation in Trp requirements for young pigs. This variation may be dependent on many factors apart from the diet itself. These factors include environment, genetics, and weight and age of the pig. Although estimating the requirement of any amino acid should seem straight forward, it is not. It is important that the basal Trp-deficient diet, when supplemented with L-Trp, provides growth performance equal to a conventional positive control diet.

Ball and Bayley (1984) estimated the Trp requirement of 2.5-kg pigs using oxidation of Phe as the response variable. A skim milk-dextrose diet was used. The recovery of CO_2 indicated that the total Trp requirement was 0.20%. This estimate is lower than the requirement estimate we obtained (0.24% total Trp) in 5.2- to 7.3-kg pigs.

Burgoon et al. (1992) estimated the dTrp requirement of starting, growing, and finishing pigs. In this experiment, growth and digestion trials were used. A corn, fish meal, and corn gluten meal diet was used, and the requirement of pigs weighing 6 to 16 kg was estimated to be 0.15%, which is substantially lower than that of both the NRC (1998) recommendation and the results we obtained in 6.3- to 10.2-kg pigs.

Han et al. (1993) estimated the apparent ileal digestible Trp requirement of pigs weighing 10 to 20 kg. This weight range is similar to the pigs we used. Broken-line regression resulted in an estimate of 0.14% apparent digestible Trp for 10-kg pigs fed an 18% CP diet.

Boomgaardt and Baker (1973) estimated the requirement of 11-kg pigs to be 0.119% total Trp for pigs fed a corn-gelatin-based diet with 18% CP. Three levels of CP (10, 14, and 18%) were used, and the Trp requirement estimate at each level was 0.071, 0.094, and 0.119%, respectively.

More recently, lower estimates ranging from 0.14 to 0.16% total Trp have also been reported for young pigs (LaRue et al., 1985; Borg et al., 1987; Sato et al., 1987). As indicated previously, these low estimates of the Trp requirement may be due to basal diet composition, Trp availability, or general differences from study to study. As a result, it is difficult to provide a definitive Trp requirement estimate that will optimize growth performance of all young pigs. Factors such as age, weight, and protein content of the diet will affect the estimate. In addition, it is likely that the requirement of a pig 20 yr ago is different from that of a pig produced today based on an increased genetic potential for lean growth.

Based on the results of our experiments with the age, weight, and breed of pigs used, the true dTrp requirement of pigs weighing 5.2 to 7.3 kg (Phase I), 6.3 to 10.2 kg (Phase II), and 10.3 to 15.7 kg (Phase III) pigs is 0.21, 0.20, and 0.18%, respectively.

Implications

The true digestible tryptophan requirement of Phase I, II, and III pigs was determined to be 0.21, 0.20, and 0.18%, respectively. When formulating diets for these ages of pigs, the use of these estimates will result in optimal growth performance. These estimates are similar to the recommendations of the National Research Council.

Literature Cited

AOAC. 1990. Official Methods of Analysis. 15th ed. Association of Official Analytical Chemists, Arlington, VA.

Baker, D. H., D. H. Becker, H. W. Norton, A. H. Jenson, and B. G. Harmon. 1969. Lysine imbalance of corn protein in the growing pig. J. Anim. Sci. 28:23–26.

Ball, R. O., and H. S. Bayley. 1984. Tryptophan requirement of the 2.5-kg piglet determined by the oxidation of an indicator amino acid. J. Nutr. 114:1741–1746.

Boomgaardt, J., and D. H. Baker. 1973. Tryptophan requirements of growing pigs at three levels of dietary protein. J. Anim. Sci. 36:303–306.

Borg, B. S., G. W. Libal, and R. C. Wahlstrom. 1987. Tryptophan and threonine requirements of young pigs and their effects on serum, calcium, phosphorus and zinc concentrations. J. Anim. Sci. 64:1070–1078.

Burgoon, K. G., D. A. Knabe, and E. J. Gregg. 1992. Digestible tryptophan requirements of starting, growing, and finishing pigs. J. Anim. Sci. 70:2493–2500.

Han, Y., T. K. Chung, and D. H. Baker. 1993. Tryptophan requirement of pigs in the weight category 10 to 20 kilograms. J. Anim. Sci. 71:139–143.

Laborde, C. J., A. M. Chapa, D. W. Burleigh, D. J. Salgado, and J. M. Fernandez. 1995. Effects of processing and storage on the measurement of nitrogenous compounds in ovine blood. Small Ruminant Res. 17:159–166.

LaRue, D. C., T. D. Tanksley, Jr., and D. A. Knabe. 1985. Tryptophan requirement of starter pigs fed a corn-soybean meal diet. J. Anim. Sci. 61(Suppl. 1):314 (Abstr.).

Leibholz, J. 1981. Tryptophane requirements of pigs between 28 and 56 days of age. Aust. J. Agric. Res. 32:845–850.

NRC. 1998. Nutrient Requirements of Swine. 10th ed. National Academy Press, Washington, DC.

Robbins, K. R. 1986. A method, SAS program, and example for fitting the broken-line to growth data. Univ. of Tennessee Agric. Exp. Sta. Rep. Knoxville. pp 86–89.

Sato, H., T. Kobayashi, R. W. Jones, and R. A. Easter. 1987. Tryptophan availability of some feedstuffs determined by the pig growth assay. J. Anim. Sci. 64:191–200.

Schutte, J. B., A. J. M. A. Verstraten, N. P. Lenis, J. De Jong, J. T. M. Van Diepen. 1995. Requirement of young pigs for apparent ileal digestible tryptophan. Neth. J. Agri. Sci. 43:287–296.

Zimmerman, D. R. 1975. Tryptophan requirements of 5- to 15-kg pigs with semipractical pig starters. J. Anim. Sci. 40:875–879.